Mapping of Soils and Bedrock Sensitivity to Acidic Deposition in Manitoba

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MAPPING OF SOILS AND BEDROCK SENSITIVITY TO ACIDIC DEPOSITION IN MANITOBA

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ABSTRACT

The Manitoba Department of Environment and Workplace Safety and Health and the Canada-Manitoba Soil Survey cooperatively developed two maps to reflect soils and geological sensitivity to acidic deposition in Manitoba. One map entitled "Sensitivity of Soils to Acidic Inputs" was intended for interpretation of sensitivity to terrestrial systems and reflects possible effects on forest or agricultural productivity. A second map, "Potential of Soils and Bedrock to Reduce the Acidity of Incoming Acidic Deposition" was developed to rate soils, surficial and bedrock geology for their potential to reduce incoming acidic deposition prior to its entry into aquatic ecosystems. The maps are at a scale of 1:2,000,000 and have been compatibly developed with other provincial jurisdictions of Western Canada. In consideration of surface soils and bedrock characteristics, areas of high sensitivity to acidic deposition were located on the east side of Lake Winnipeg and in the northwest corner of the province. In these areas the potential of soils and bedrock to reduce the acidity of incoming acidic deposition is low, similarly indicating a high sensitivity.

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1. INTRODUCTION

Prior to 1980 little information was available on the potential impacts of acidic deposition on terrestrial ecosystems. It was recognized that inherent properties of natural soil and geologic material and resultant reactions would alter the ultimate fate of incoming acidic compounds from atmospheric processes.

Basic to understanding the extent and distribution of potential impacts of acidic deposition to terrestrial systems and the importance of such systems in interception and transformation of acidic compounds was the need to delineate sensitive areas. Initial sensitivity mapping was completed in 1983 for Eastern Canada as part of the Memorandum of Intent, MOI (Bangay and Riordan 1983).

It was clearly noted in the MOI that sensitivity mapping had been carried out in the presence of great uncertainties about soil and geology response to acidic inputs and an even larger number of uncertainties about relationships between soil and geology acidification and plant growth, or drainage water composition.

Initial sensitivity mapping efforts in Eastern Canada have been carried further in the provinces of Ontario, Quebec and Nova Scotia from 1983 to present. In 1981 the need for compatible mapping was recognized in Western Canada and was addressed by the Consultative Committee - Western Canada Long Range Transport of Air Pollutants (LRTAP).

This Committee composed of deputy ministers from the provinces of British Columbia, Alberta, Saskatchewan, Manitoba, the Northwest Territories, and senior officials from Environment Canada together with its Technical Committee, coordinates monitoring, research and other acid rain related activities in the west. The mandate for sensitivity mapping was initiated by these two committees with the signing of the first three year research program for LRTAP in Western Canada, 1982-1985.

The objectives of this research program were to identify current conditions in Western Canada, and to provide information necessary for the respective jurisdictions to develop appropriate management strategies. Maps of soil and geology sensitivity were among the six program priorities. In late 1981 the Technical Committee appointed a Coordinating Committee for Soil and Geology Sensitivity Mapping composed of scientists from Manitoba, Saskatchewan, Alberta, British Columbia, Northwest Territories and Environment Canada.

This group was responsible for reviewing previous mapping efforts in Eastern Canada and for establishing methodologies and criteria to complete compatible sensitivity mapping in Western Canada. Each provincial and territorial jurisdiction was responsible for completion of mapping in their respective area.

In the province of Manitoba the mapping of soils and geological characteristics sensitive to acidic deposition or the long range transport of air pollutants has been a cooperative endeavour between

the Manitoba Department of Environment and Workplace Safety and Health and the Canada-Manitoba Soil Survey. Two interpretive maps have been produced at a scale of 1:2,000,000 concurrently with other provincial and territorial jurisdictions in Western Canada:

(1) Sensitivity of Soils to Acidic Inputs

and

(2) Potential of Soils and Bedrock to Reduce the Acidity of Incoming Acidic Deposition

The mapping of soil and geology characteristics is required to delineate the extent and distribution of terrestrial systems which are potentially sensitive to the effects from the atmospheric deposition of acidic compounds. Mapping in addition to providing a base for future monitoring also provides an opportunity to review existing soil and geology information in terms of characteristics useful for environmental degradation studies.

In particular sensitivity mapping provides information for delineating areas where high acidic inputs and high sensitivities correspond and therefore more intensive investigation and perhaps control measures are required. Sensitivity mapping provides a base for future site specific and more detailed investigation as well as a regional perspective to facilitate planning and management of sensitive terrestrial environments.

2. OBJECTIVES OF SENSITIVITY MAPPING

It is recognized that objectives, definitions and uses of sensitivity maps for terrestrial ecosystems will vary. Most commonly one or more terrestrial components are targetted for sensitivity rating and mapping whether it is soils, geology, forest productivity or agriculture. A single sensitivity map is unlikely to serve all purposes. In compliance with the Coordinating Committee for Soils and Geology Sensitivity Mapping in Western Canada two maps at scale of 1:2,000,000 were developed to provide a logical compromise based on best available information interpreted with the following objectives:

(1) SENSITIVITY OF SOILS TO ACIDIC INPUTS

To identify and rate soils to changes in physical, chemical and biological properties to reflect possible effects to forest or agricultural productivity. Soil sensitivity is defined as an expression of the respective susceptibilities of different soils to changes in one or more of the following: soil acidification and pH reductions; mobilization of exchangeable bases; and solubilization of aluminum in response to a given input of acidity.

(2) POTENTIAL OF SOILS AND BEDROCK TO REDUCE THE ACIDITY OF INCOMING ACIDIC DEPOSITION

To identify and rate soils, surficial and bedrock geology for their potential to buffer or neutralize incoming acidic compounds prior to their entry into the aquatic regime. This is based on the premise that the chemical composition of soils, geology and bedrock, the depth of soil, and the bedrock type within each area will provide the best indication of the long term capacity of watersheds to buffer acidic deposition.

3. METHODOLOGIES - WESTERN CANADA

3.1 BACKGROUND

The first task of the Soil and Geology Coordinating Committee was to assemble and review soil and geology mapping information available as a data base in each of the four western provinces, the Yukon and the Northwest Territories. A report was released in late 1981 (Wotton, 1981) and was followed by a second report outlining general agreements and outstanding issues relative to proceeding with a coordinated approach to sensitivity mapping (Wiens, 1982).

During 1983 and 1984 the committee reviewed sensitivity mapping efforts in Eastern Canada, defined sensitivity classification criteria and established acceptable sensitivity classes. Criteria and methodologies were initially based on those employed in Eastern Canada (Bangay and Riordan, 1983, Coote et al. 1981 a, Cowell et al. 1981, Lucas and Cowell, 1984, Shilts et al. 1981, Wang and Coote, 1981). However, variation in available data base and topographical features in the west necessitated some modification to these methodologies to ensure compatible mapping acceptable to all jurisdictions of Western Canada (Wiens, 1983).

The four western provinces agreed to produce the two selected interpretive maps at a scale of 1:2,000,000. The Northwest Territories and the Yukon due to a more limited data base were to develop maps at a scale 1:5,000,000. Following completion of these

maps by the individual jurisdictions then a composite map for Western Canada is to be produced at a scale of 1:5,000,000 by the Soils and Geology Coordinating Committee.

3.2 SOIL SENSITIVITY CRITERIA

Three principal soil chemical processes were accepted to evaluate the sensitivity of acidic deposition to terrestrial ecosystems: soil acidification and pH reduction, base cation loss, and aluminum solubilization. Individual sensitivities to these internal soil characteristics were evaluated and combined into a single interpretation for evaluation of agricultural, forest and natural vegetation productivity.

The criteria for separately rating sensitivity of soils is found in Table 1 and and several points in respect to interpretation should be emphasized. The criteria attempt to integrate or combine soils and geology information in a systematic way to arrive at a single sensitivity rating. Adoption of these criteria require that each map unit be defined for characteristics of soil chemistry (exchangeable bases or surrogates), soil depth, bedrock exposure and bedrock type. This definition may be attained directly from source maps or indirectly from inference.

For the map to be representative of forest and agricultural sensitivity certain assumptions for interpreting sensitivities of soil processes were adopted. These assumptions are:

Table 1: Criteria for Rating the Sensitivity of Soils to Acidic Deposition*

CEC (meq/100g)	pH	Base Loss	Acidification	Al Solubilization	Overall Sensitivity
<6	<4.6	H	L	H	H
	4.6-5.0	H	L	H	H
	5.1-5.5	H	M	H	H
	5.6-6.0	H	H	M	H
	6.1-6.5	H	H	L	H
	>6.5	L	L	L	L
6-15	<4.6	H	L	H	H
	4.6-5.0	M	L	H	M
	5.1-5.5	M	L-M	M	M
	5.6-6.0	M	L-M	L-M	M
	>6.0	L	L	L	L
>15	<4.6	H	L	H	H
	4.6-5.0	M	L	H	M
	5.1-5.5	M	L	M	M
	5.6-6.0	L	L-M	L-M	L
	>6.0	L	L	L	L

* Sensitivity Code: H - High, M - Moderate, L - Low

- High sensitivity for already acid soils, or mineral soils with a low cation exchange capacity (CEC). It is assumed that the soils will have a potential for high levels of Al which will cause decreased productivity.

- High sensitivity for soils sensitive to base cation loss where the amount of base is initially low (i.e. low CEC and/or low initial pH, therefore low base saturation). Although soil sensitivity to base cation loss is significant, it must be considered in combination with CEC and initial pH.

3.3 SOIL AND BEDROCK SENSITIVITY CRITERIA

Methodologies and criteria developed for Eastern Canada through the MOI exercise were adopted where terrain characteristics are approached on a holistic base and the result is the map, "The Potential of Soils and Geology to Reduce the Acidity of Incoming Acidic Deposition".

Soil and geologic information are recognized as the best indicators of the long term capacity of watersheds to buffer acidic deposition. This map was therefore developed for interpretation of sensitivity to aquatic systems. The rating of potential to reduce acidity was based primarily on bedrock characteristics, on a combination of bedrock and soil characteristics, and/or primarily on soil characteristics.

The criteria for rating soils and bedrock is found in Table 2. The rating system developed is based on the assumption that water moving through the terrestrial system may contact soil, surficial geologic material and bedrock as it makes its way to surface water systems and each component is rated respectively. Knowledge of soil properties such as pH, exchangeable bases, cation exchange capacity, texture and underlying bedrock type are incorporated into rating each map unit.

Table 2: Terrestrial Factors and Associated Criteria for Determining the Potential of Terrestrial Ecosystems to Reduce Acidity of Atmospheric Deposition (Modified after Cowell et al. 1981).

TERRESTRIAL FACTORS	POTENTIAL TO REDUCE ACIDITY OF ATMOSPHERIC DEPOSITION		
	HIGH	MODERATE	LOW
Soil Chemistry			
i) Exchangeable Bases (meq/100g)	>15	6 to 15	<6
Surrogates:			
(a) Family Particle Size and pH in water.	clayey, pH >5.0 loamy, pH >5.5 all calcareous soils	clayey, pH 4.5 to 5.0 loamy, pH 5.0 to 5.5 sandy, pH >5.5	clayey, pH <4.5 loamy, pH <5.0 sandy, pH <5.5
(b) Texture	clay, silty clay, sandy clay (>35% clay)	silty clay loam, clay loam,	silt, sandy loam, loamy sand, sand (<10% clay)
(c) Cation Exchange Capacity	>25 meq/100g	10 to 25 meq/100g	<10 meq/100g
ii) SO_4^{-2} Adsorption Capacity		high sulphate adsorption:	
low sulphate adsorption:	low organic matter AND high Al_2O_3 and/or Fe_2O_3 + Fe_3O_4 content	———	high organic matter AND/OR low Al_2O_3 and/or Fe_2O_3 + Fe_3O_4 content
Soil Depth (cm)	>100	25 - 100	<25
Soil Drainage	poor	imperfect to well	rapid
Landform Relief	level	rolling	steep
Vegetation	deciduous	mixed	coniferous
Vegetation Cover	continuous (>60%)	discontinuous to sparse	sparse to barren (<20%)
Underlying Material			
i) Parent Material	carbonate bearing	non-carbonate bearing	non-carbonate bearing
ii) Bedrock Material	limestone, dolomite, and metamorphic equivalents, calcareous clastic rocks, carbonate rocks interbedded with non-carbonate rocks	volcanic rocks, shales, greywackes, sandstones, ultramafic rocks, gabbro, mudstone, metaequivalents	granite, granite gneiss, orthoquartzite, syenite

4. METHODOLOGIES - MANITOBA

4.1 BACKGROUND

The Environmental Management Division of the Province of Manitoba cooperatively addressed the task of sensitivity mapping in the province with the Canada-Manitoba Soil Survey. Both agencies worked in advisement with the Geological Services Branch, Department of Energy and Mines, Province of Manitoba.

The Canada-Manitoba Soil Survey initially evaluated the Generalized Soil Landscapes Map of Manitoba to produce a first draft working document in 1981. A review of mapping efforts in eastern Canada in response to the Memorandum of Intent (Bangay and Riordan, 1983) was carried out concurrently with other provincial jurisdictions. Base documents of principal review for bedrock mapping were by Shilts (1981) and for terrestrial mapping were by Coote et al. (1981, b), Cowell et al (1981), Lucas and Cowell (1982), and Wang and Coote (1981).

In 1983 following the working group meeting of the Coordinating Committee the initial working map was refined and updated to reflect the accepted criteria for western Canada. The following sources of information were then used to develop the terrestrial sensitivity maps of Manitoba.

1. Base Map - Generalized Soil Landscape Map, Extended Legend.
2. Soil Survey Reports, Maps and Analytical Data.
3. Soil Test Information on pH, Carbonate and Texture.

4.2 CRITERIA INTERPRETATION

4.2.1 SOIL SENSITIVITY TO ACIDIFICATION

The rationale and criteria adopted by the Coordinating Committee was followed for interpretation of the Manitoba data base. A generalized soil landscapes map (1:2,000,000) and legend provided basic information on dominant and sub-dominant soil and/or bedrock components, texture and carbonate level for map delineations. Soils of similar development, surface texture and carbonate level were grouped into map units. Analytical data for cation exchange capacity (CEC), pH and surface texture was summarized for each map unit from published soil survey reports and from soil data files. This procedure allowed for more precise values to be assigned to parameters required to rate map units for sensitivity to base loss, acidification (pH change) and aluminum solubilization. Soil sensitivity classes (low, moderate and high) were a synthesis of the ratings for individual factors as outlined in Table 1.

In applying the criteria to rate map units several considerations were important. (a) The soil properties of the surface 20 cm were most important in application of the criteria. (b) Whenever dominant and sub-dominant soil and/or bedrock components exhibited similar properties a single class rating was assigned. (c) A map unit with two class ratings indicates a condition where dominant and sub-dominant components were rated in separate classes because of different soil properties. The first class accounts for 50% or more of the soils and the second class at least 20%. (d) Cryosolic soils

Table 3: Guide for Assigning Soil Sensitivity Classes in Manitoba.*

	HIGH SENSITIVITY	MODERATE SENSITIVITY	LOW SENSITIVITY
(i)	DYSTRIC BRUNISOLS (S, LS, associated with acid bedrock and organic soils)	EUTRIC BRUNISOLS (S, LS, and SL with carbonate free surface)	EUTRIC BRUNISOLS (L, high carbonate in subsurface)
(ii)	ORGANICS (BOG) (associated with acid bedrock, organics (fen) and luvisols)	ORGANICS (FEN) (associated with organic (bog) and luvisols)	
(iii)	CRYOSOLS (LS, associated with dystric brunisols)		
(iv)		BLACK CHERNOZEMS (Gr. S, S, LS, well drained)	BLACK CHERNOZEMS (SL, L, CL and C, with carbonates at or near the surface)
(v)		REGOSOLS (Gr. S, S, LS, well drained, eolian)	REGOSOLS (L, CL and C)
(vi)		DARK GREY CHERNOZEMS OR LUVISOLS (S, LS and SL)	
(vii)		GRAY LUVISOLS (LS, SL, L and CL and northern clay textured luvisols associated with organic soils and/or acid bedrock)	
(viii)			BLACK SOLONETZIC (L and CL)
(ix)			GLEYSOLS (all surface textures)
(x)	BEDROCK (ACID) (mainly non carbonate bearing rocks, i.e. granite, granite gniess, orthoquartzite, syenite)		BEDROCK (CARBONATE) (mainly limestone, dolomite and morphic meta equivalents)

* SURFACE TEXTURE

S	= Sand	SL	= Sandy Loam
LS	= Loamy Sand	CL	= Clay Loam
Gr. S	= Gravelly Sand	C	= Clay
L	= Loam		

were rated based on soil pH and cation exchange capacity properties. The cryogenic condition of the soil was not incorporated into the sensitivity rating. Table 3 provides a guide for assigning soil sensitivity classes to map units based on soil development and surface texture.

In general, the low sensitivity class was comprised of soils with a cation exchange capacity greater than 15 meq/100g, high amount of exchangeable bases and pH values greater than 6.0. Soils with carbonates present to the surface and carbonate bearing bedrock were placed into the low sensitivity class.

Soils rated as moderately sensitive have cation exchange capacities of 6 to 15 meq/100g, exchangeable bases are moderately high and pH values are in the range of 4.6 to 6.0. Surface textures of soils are usually sand, loamy sandy and sand loam, and carbonates are present in the subsurface. Some finer textured soils with leached surface conditions and usually associated with organic soils were placed in the moderate class. Organic (fen) soils were also placed into the moderate category.

The high sensitivity class contained soils that are acid in nature, sand, loamy sand and sandy loam in texture. Many of these soils are associated with organic soils and acidic bedrock. Measured chemical data indicate an average cation exchange capacity value of 8.0 meq/100g and an average pH value of 4.5.

4.2.2 POTENTIAL OF SOILS AND BEDROCK TO REDUCE ACIDITY.

Map units were rated into three classes (low, moderate, and high) for soils and into two classes (low or high) for bedrock by applying the criteria provided in Table 2. In areas with two ratings, the first rating is considered to account for 50% or more of the area, and the second at least 20%. The influence of soil and bedrock to a depth of 2 meters was used to rate areas into classes.

A low potential to reduce acidity was assigned to soils that are generally acidic (pH<5), coarse textured (sand, loam/sand, sandy loam) and have a low cation exchange capacity (≈8meq/100g). Organic (bog) soils were included in this class because of their acid nature and low base status. Map units dominated by acid bedrock were also rated to have a low potential to reduce acidity.

A moderate potential to reduce acidity was assigned to areas with soils that are slightly acidic and contain a moderate amount of exchangeable bases. Organic soils, many of which extend beyond the control section of 2 meters, were rated in the moderate class.

However, underlying inorganic materials may have a high capacity to reduce acidity and this condition has been noted. Clay textured luvisolic soils associated with organic soils in northern Manitoba were assigned a moderate rating. It was assumed that rapid downward movement of soil water would be restricted by the compact clay and that lateral flow through the non-carbonated upper zone may be a significant factor in water movement to lakes and streams.

A high potential to reduce acidity was assigned to soils high in exchangeable bases and with carbonates present in the subsurface. Bedrock containing limestone, dolomite and other carbonate bearing rocks was also rated to have a high potential to reduce acidity.

5. SUMMARY - MANITOBA MAPPING

(i) Sensitivity of Soils to Acidic Inputs

Soils in the low sensitivity or non-sensitive class are soils generally high in clay and/or organic matter. These soils have a high buffering capacity, a high content of exchangeable bases (>15 meq/100g), and some soils are calcareous. The soils of the southern, interlake and western regions of Manitoba were found to be predominantly non-sensitive.

Soil in the moderate class are slightly to strongly acidic, have a moderate base content (6-15 meq/100g) and a moderate buffering capacity. Areas of moderate sensitivity are generally composed of acid organic soils in the northern area of Manitoba and in the area adjacent to Lake Winnipeg. In the agricultural region of the province, coarse textured (sand, loamy sand) well drained soils and soils with a strong evidence of surface leaching were rated as moderate or moderate-low in sensitivity. In map areas containing two classes, the first class accounts for 50% or more of the soils, and the second at least 20%.

The highly sensitive class of soils are sandy, low in organic matter, very strongly to slightly acidic and generally associated with Precambrian bedrock. These soils have a low content of exchangeable bases (<6 meq/100g) and a low buffering capacity. Two areas of high sensitivity were identified, an area east of Lake Winnipeg and an area in the northwest corner of the province.

(ii) Potential of Soils and Bedrock to Reduce the Acidity of Incoming Acidic Deposition.

Soils and bedrock were defined in terms of low, moderate and high classes. Combinations of both soils and bedrock are indicated on some map areas. In areas containing two ratings, the first rating is considered to account for 50% or more of the area, and the second at least 20%.

Soils and bedrock rated as having a low potential to neutralize incoming acidity correspond to soils rated as having a high sensitivity to acidic deposition resulting from the long range transport of air pollutants. In Manitoba, such areas are found on the east side of Lake Winnipeg and in the northwest corner of the province similar to the soil sensitivity map.

Areas rated as having a moderate potential to reduce acidity are dominantly comprised of organic soils. Areas classified as moderate are found adjacent to and north of Lake Winnipeg as well as in the northeastern area of the province.

Soils containing carbonates and/or limestone bedrock are rated as having a high potential to reduce acidity and therefore a low sensitivity to incoming acidic compounds. In Manitoba the southern and southwestern region of the province is found to be of a high potential to reduce acidity or low in sensitivity.

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MAPS NOT

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